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A Testbed for Autonomous Mining Machine Experiments

By William H. Schiffbauer

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

A	ampere	psi	pound per square inch
°F	degree Fahrenheit	psia	pound per square inch, absolute
ft	foot	s	second
gpm	gallon per minute	st	short ton
in	inch	v	volt
µm	micrometer	w	watt
Mb	megabyte		
MHz	megahertz		

A TESTBED FOR AUTONOMOUS MINING MACHINE EXPERIMENTS

By William H. Schiffbauer[1]

ABSTRACT

The Bureau of Mines is conducting research that is aimed at making the mining industry more efficient in terms of both productivity and the health and safety of the worker. As part of this research the Bureau of Mines has integrated a testbed composed of computer and related peripheral hardware to form an intelligent base for performing autonomous mining machine experiments. Although this particular application was configured for use on a Joy 16 CM mining machine, its generic structure facilitates its attachment to a variety of mining machine types. The multitasking multiuser computer can be set up for other applications by changing a bubble memory cartridge. The Joy 16 CM implementation includes 96 digital input-output (I-O) ports, 32 analog inputs, 8 analog outputs, 2 serial data channels, and 1 printer port. Operation of the machine can be performed either through a local terminal or remotely through a modem hookup. This report describes a testbed for autonomous mining machine experiments (TAMME)--its hardware, software, and complete system integration--so that it can be used as a foundation for other applications.

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INTRODUCTION

Major problems threaten today's coal mining industry. Most of these problems can be traced to basic economics; i.e., providing a product that is both competitive and profitable. Through research, the Bureau of Mines is developing methods and devices that show promise in assisting private industry in making a competitive and profitable product, and also helping the workers to achieve these goals in a safe working environment.

The TAMME system developed by the Bureau shows great promise toward making mining machinery more productive and safe for the workers by enhancing it with the latest computer technology. The TAMME is a collection of computer and peripheral devices, integrated into one chassis, and programmed to operate a Joy 16 CM mining machine (fig. 1). A modular I-O structure permits attachment of TAMME to present and future monitoring or control devices. The hardware selected employs transformer and optical coupling, providing extreme isolation from the noisy electrical environment presented by a mining machine. Additionally, a special power supply is used. The power supply, with transformer isolation and special circuit design, prevents any power fluctuations from entering the TAMME chassis. Throughout the hardware and software are a variety of diagnostic features that give the operator a status report of system health. Included in the design is a removable storage device called a bubble memory cartridge, that provides storage of operating system and application programs. The flexibility provided by TAMME allows it to be reconfigured for almost any monitoring and control application.

The Bureau has created a tool that is useful for both research and production. It was constructed from a variety of off-the-shelf hardware and software so that its structure can be duplicated with a minimum of customization. Although this application of TAMME was specific to a Joy 16 CM mining machine, it can be easily applied to other mining machine types through modification of the software.

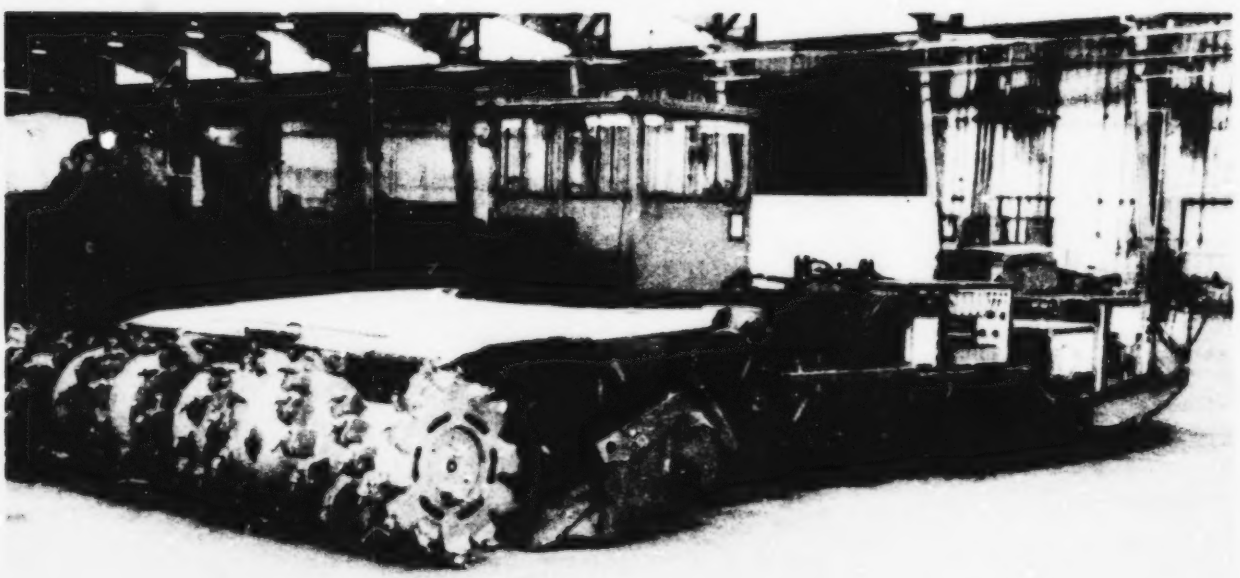

FIGURE 1.—Joy 16 CM mining machine.

DESIGN OBJECTIVES

The creation of TAMME was initiated to provide a base or testbed on a mining machine to allow Bureau researchers to experiment with making mining machinery autonomous, with the purpose of increasing production and making mining safer. The testbed was constructed with the latest technology and standardized interfaces so that the product could evolve with the types of experiments being performed. The first step of the process was to establish control of the primary appendages of the machine without worrying about the actual position of the appendages. Then, with the help of the appropriate sensors, all of the appendages and crucial systems on the machine were to be monitored, including the electrical and hyraulic systems. Next, closed loop control of the primary appendages of the machine was to be established using the output of the sensors as a verification of position. The next objective was to produce a scripting mode of operation, to demonstrate a series of mining cycles completely controlled by the computer. This objective would be the starting point of the next phase of this ongoing research.

Additionally, a major goal was to document TAMME so that industry personnel could duplicate and use it on their own machines for research or production.

OPERATING SYSTEM SOFTWARE DESCRIPTION

An Intel Corp.[2] iRMX86 operating system was used to form the software foundation for controlling the TAMME system. The iRMX86 was used because it is a real-time, multitasking, multiuser, custom-configurable operating system designed to support high-performance, time-critical applications. Because both iRMX86 and the host central processing unit (iSBC 286/12) are provided and supported by the same manufacturer, their choice as a team minimized the hardware-software failure bottleneck usually associated with system development.

The customized iRMX86 operating system used on TAMME is activated on powerup. Once activated it creates a collection of simultaneously executing software applications, called jobs, that provide software interfaces to the various pieces of the TAMME system. The jobs most visible to the system user are the human interface job and the extended I-O job. Other jobs are created but their purposes are beyond the scope of this paper.

The human interface job gives the users and applications simple access to file and system management capabilities. Using support from other iRMX86 jobs, the human interface provides two simultaneous users for the TAMME system, a local user and a remote user.

The extended I-O job is a group of software modules that provide users with system calls for direct management of hardware including the bubble memory, random access memory (RAM), interrupts, and I-O devices.

Figure 2 shows the operating system environment and the hardware peripheral devices.

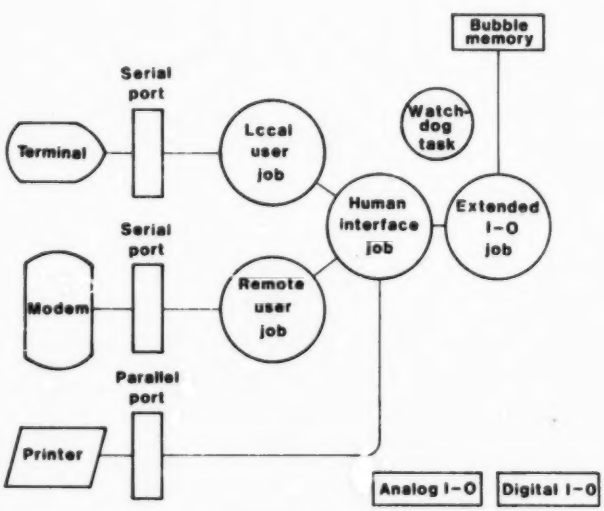

FIGURE 2.–Operating system and hardware devices.

[2]Reference to specific products does not imply endorsement by the Bureau of Mines.

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PROGRAMMING LANQUAGE DESCRIPTION

All of the application programs created for TAMME were done in the PLM 86 programming language. PLM 86 is an Intel microcomputer-specific, block-structured, high-level language, that provides full access to the microcomputer architecture.

Use of PLM 86 simplified the process of breaking up the software into individual modules dedicated to specific system tasks, which speeds up software production and minimizes bugs.

HARDWARE DESCRIPTION

A large collection of hardware formed the TAMME system. Hardware selection was carefully done to provide a base that was modular and standardized so that it could be reconfigured to an evolving series of experiments with a minimum of complications. A portion of the TAMME system was designed using a previous Bureau development as a guide.[3] The present package of hardware is shown in figure 3. A description of each of the components used to construct TAMME follows.

[3]Schiffbauer, W. H. An Intelligent Remotely Operated Controller for Mining Machines. Paper in Proceedings of the Third Conference on the Use of Computers in the Coal Industry, ed. by Y. J. Wang, R. L. Grayson, and R. L. Sanford. A. A. Balkema, 1986, pp. 223-233.

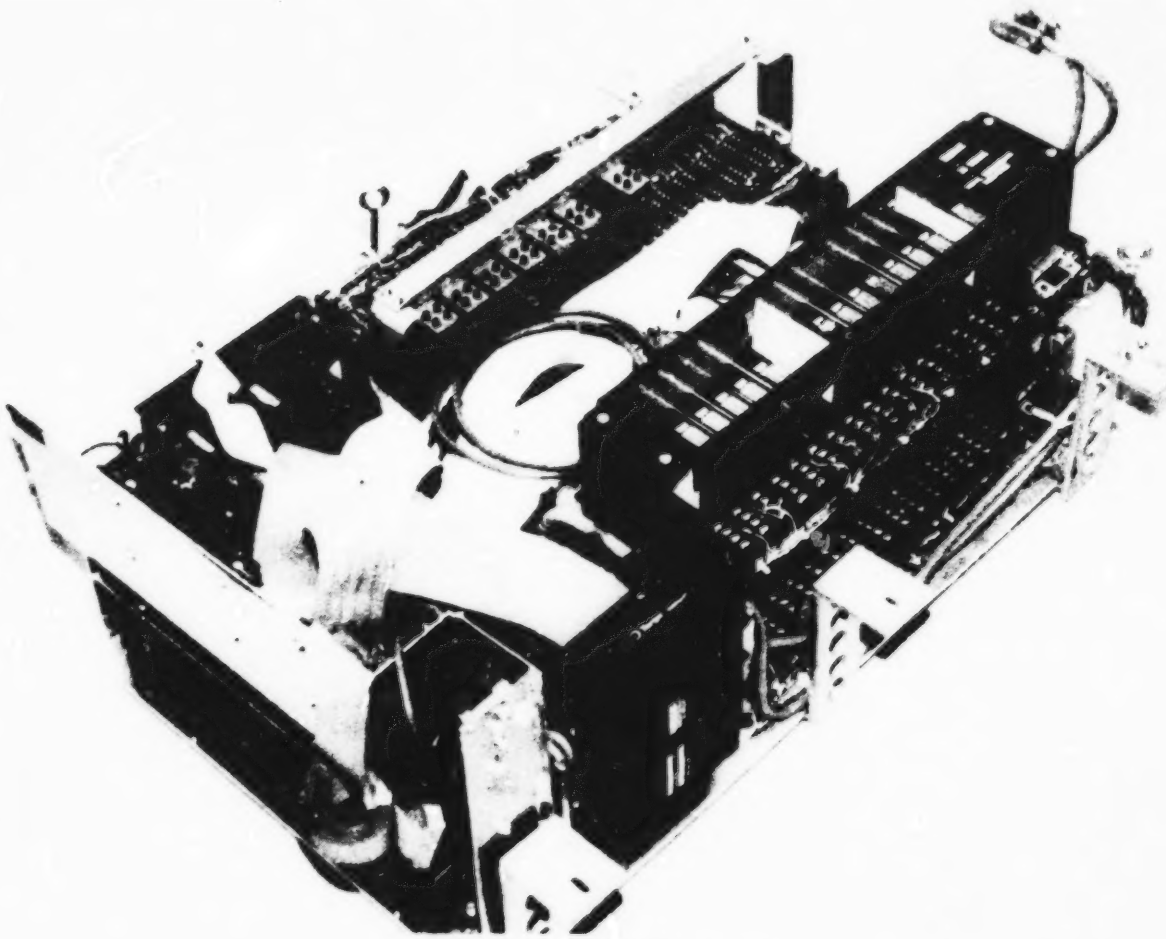

FIGURE 3.–TAMME hardware.

Multibus I Backplane, Electronic Solutions, Nine-Slot Chassis

Multibus I is an industry standard[4] microcomputer bus structure, that supports distributed processing configurations using multiple processors, I-O boards, and peripheral boards.

Multibus I was selected because of its extreme adaptability, and the large number of commercially available devices that conform to this standard.

Central Processing Unit (CPU) board, Intel iSBC 286/12

The iSBC 286/12 single-board computer is a high-performance 16-bit microcomputer. It includes an 8-MHz 80286 microprocessor, together with a high-performance 80287 numeric data coprocessor and 1 Mb of zero-wait state memory. Additionally, it has multiple serial and parallel expansion ports, and other expansion capabilities through two multimodule bus connections and the multibus card edge interface.

The iSBC 286/12 card was the choice for TAMME system because at the time of selection, it was the newest state-of-the-art microcomputer board that could provide a real-time control system.

Bubble Memory, TARGA Electronics, Solidrive

The Solidrive consists of a removable 0.5 Mb bubble cartridge and a drive chassis. The drive chassis is mechanically and electrically configured to replace a standard 5-1/4-in half-height floppy disk drive. The bubble cartridge is used just as a floppy disk is used.

The data stored in the bubble cartridge are permanently retained in the nonvolatile, solid-state, magnetic bubble memory. Once stored, data will be retained indefinitely without external power until they are intentionally overwritten or erased. The contents of the bubble cartridge may be altered as often as is required since bubble memory is not subject to read-write-erase wear out.

The bubble memory cartridge was chosen over a floppy disk or Winchester disk, because bubble memory is immune to the effects of mechanical vibration because it has no moving parts. Figure 4 shows the Solidrive and the bubble memory cartridge.

Sensor Conditioning Modules, Analog Devices, 3B series

Each of the sensors attached to the mining machine are connected to TAMME through a conditioning module (see table 1). The 3B series of conditioning modules were chosen because they use transformer coupling, which provides maximum mining machine electrical system isolation, and also because there are modules available for a large variety of sensor types.

Analog-to-Digital Converter Card, Analog Devices, RTI 711

The RTI 711 is a complete single-board analog input card that interfaces with multibus-compatible computer hardware. It provides 32 channels of 12-bit resolution, single-ended inputs, and has high common mode noise rejection.

The RTI 711 was selected because it was compatible with the remainder of the system, required only a single supply voltage, and its power consumption was quite low.

Digital-to-Analog Converter Card, Intel iSBX328

The iSBX 328 is a 16-channel 12-bit resolution device.

This digital-to-analog converter was selected over other devices because of the number of channels provided in a compact package.

[4]Institute of Electrical and Electronic Engineer, IEEE Standard 796, System Backplane Bus.

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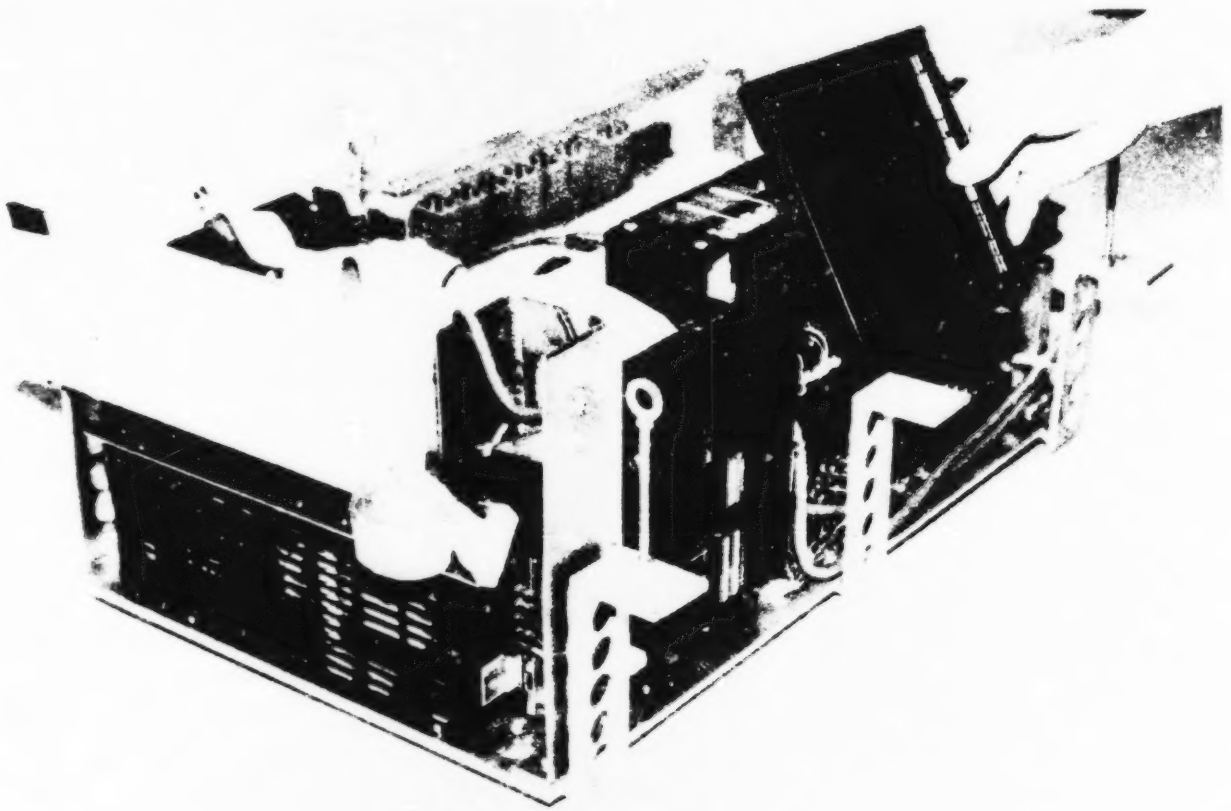

FIGURE 4.--Bubble memory cartridge.

Digital Input-Output, Opto 22

Opto 22 devices are a series of removable input or output modules that are optically isolated and can be used for both ac and dc signals with resistive and inductive loads. They provide complete electrical isolation between the computer to the control system, a main reason for their choice for the TAMME system.

The TAMME system is presently configured to provide up to 96 inputs-outputs. The assignment of channels for the Joy 16 CM machine is shown in table .

Uninterruptible Power Supply (UPS), TII Electronics

The 170-W UPS provides transformer isolation from the mine power system. It eliminates virtually all transients and power fluctuations through its unique circuit design. Additionally, this UPS generates multiple dc voltages to TAMME instead of supplying ac voltages as would other power supplies. This feature eliminates an extra step in the power conversion process, makes the UPS more efficient, and consumes less power, thereby generating less heat in the computer housing.

Chassis Mounting Considerations

The Joy 16 CM mining machine is not a very good base for mounting delicate computer hardware. The extreme vibration provided by it would certainly destory an unprotected system. It has

TABLE 1. - Sensor connections to TAMME

Module[1]	Type	Function	Units
1.....	3B31-03	Conveyor elevation.....	0°-20°.
2.....	3B31-00	Conveyor swing.....	0°-95°.
3.....	3B31-03	Left cutting motor current.....	0-400 A.
4.....	3B31-03	Right cutting motor current.....	0-400 A.
5.....	3B31-00	Gathering head elevation.....	0°-25°.
6.....	3B32-01	Hydraulic reservoir level.....	0-16 in.
7.....	3B16-01	Hydraulic reservoir pressure.....	0-25 psia.
8.....	3B31-03	Hydraulic solenoids current.....	0-5 A.
9.....	3B32-02	Input line voltage.....	0-750 V.
10.....	3B31-03	Main hydraulic return flow.....	0-85 gpm.
11.....	3B31-03	Left tram motor current.....	0-100 A.
12.....	3B31-03	Right tram motor current.....	0-100 A.
13.....	3B31-03	Gathering head conveyor motor current.....	0-100 A.
14.....	3B31-03	Pump motor current.....	0-200 A.
15.....	3B16-01	Pilot filter pressure.....	0-50 psia.
16.....	3B31-01	Main pump flow.....	0-30 gpm.
17.....	3B31-01	Pilot pump flow.....	0-20 gpm.
18.....	3B31-01	Pilot pump pressure.....	0-2,000 psi.
19.....	3B31-01	Main pump pressure.....	0-4,000 psi.
20.....	3B31-01	Pilot pump temperature.....	50°-250° F.
21.....	3B31-01	Main pump temperature.....	50°-250° F.
22.....	3B31-00	Shear elevation.....	0°-50°.
23.....	3B31-03	Left tram distance.....	0°-220.5 ft.
24.....	3B31-03	Right tram distance.....	0°-220.5 ft.
25.....	3B31-03	Stabilizer elevation.....	0°-40°.
26.....	3B31-03	Stabilizer pressure.....	0-5,000 psi.

[1]Modules 27 through 32 are not used.

been determined,[5] via underground field measurements, that military standard MIL-STD-810B for tracked vehicles best represents the vibration environment for electronic components mounted on underground coal mining equipment. With the vibration environment in mind, a computer chassis was constructed and then tested on a shaker table. The results identified the vibrational frequencies of the chassis. Knowing the mining machine and the computer chassis vibrational characteristics, a special set of soft vibration mounts with mechanical stops for shock suppression (Stock Drive Products, model 10z38-0507) were procured for mounting the computer chassis on the mining machine. Their use minimized the computer chassis vibration.

[5]Bartholomae, R. C., B. S. Murray, and R. Madden. Vibration Qualification of Electronic Instrumentation for Underground Coal Mining Machinery. BuMines IC 8883, 1982, 10 pp.

TABLE 2. - Digital I-O channel assignments

Module	Function	Module	Function
Input (ODC5Q):		Input (ODC5Q)--Con.	
1.1.....	Conveyor elevation up.	5.4.....	Gathering head extension out.
1.2.....	Conveyor elevation down.	6.1.....	Not used.
1.3.....	Conveyor swing right.	6.2.....	Conveyor reverse.
1.4.....	Conveyor swing left.	6.3.....	Shear up.
2.1.....	Control safety latch.	6.4.....	Shear down.
2.2.....	Gathering head down.	7.1.....	Cutting control.
2.3.....	Gathering head up.	7.2.....	Pump run control.
2.4.....	Drum extension in.	7.3.....	Power control relay.
3.1.....	Right tram slow.	7.4.....	Conveyor forward.
3.2.....	Left tram slow.	8.1.....	Not used.
3.3.....	Right tram reverse.	8.2.....	Do.
3.4.....	Left tram reverse.	8.3.....	Do.
4.1.....	Right tram forward.	8.4.....	Do.
4.2.....	Left tram forward.	Output (IDC5Q):	
4.3.....	Tram fast.	9.1.....	Pressure switch 10-μm filter (16 psi).
4.4.....	Drum extension out.	9.2.....	Pressure switch 3-μm filter (16 psi).
5.1.....	Stabilizer jack up.	9.3.....	Pressure switch 10-μm filter (35 psi).
5.2.....	Stabilizer jack down.	9.4.....	Pressure switch 3-μm filter (35 psi).
5.3.....	Gathering head extension in.		

NOTE.--The remainder of the 96 I-O ports are presently unused.

APPLICATION SOFTWARE

MODES OF OPERATION

The applications created for TAMME are identified as modes of operation including the system diagnostics mode, the system exerciser mode, closed loop test mode, the browser mode, and the scripting mode.

Each of these modes of operation and associated piece of software permit the system operator to perform some series of tests or functions. A brief description for each of the modes of operation follows.

System Diagnostics Mode

This mode was used only in the development process and is no longer active in the system. It provided the initial checkout of hardware, and insured that all devices were connected properly. It was left in the system for future use.

System Exerciser Mode

Each of the functions on the Joy 16 CM machine normally controlled by the machine operator can be operated using this open loop mode of test. Each of the appendages can be turned on for a length of time as selected by the user. No position feedback on the controlled appendage it used. This mode was created to obtain appendage control characteristics.

Closed Loop Mode

Several of the Joy 16 CM machine appendages have sensors to validate their position. Use of this mode lets the

researcher operate the appendage under closed loop control. Characteristics such as overshoot due to gear backlash, hydraulic system response times, and other machine control variables can be analyzed using this mode of operation.

Browser Mode

Provides the operator with a quick look at the present analog voltage outputs of all of the sensors attached to the TAMME conditioning modules. Although mainly used for situation diagnostics, it can be used for more complex machine analysis.

Scripting Mode

An operator can use this software to create a complete mining cycle script by using a menu to select and then chain together several machine functions. Once a complete script is formed, it can be executed by entry of a single keystroke on the operator terminal. Each of the entries in the script will execute sequentially and will continue to the end unless terminated by the user.

SYSTEM INTEGRITY SOFTWARE

System Confidence Tests

The system confidence tests (SCT) software is resident in the firmware of the CPU board. The SCT is activated on powerup. It tests the CPU board, its memory, its interrupts, and most of the peripheral hardware. The results of the SCT are displayed on the local terminal. If no errors are detected, the operator continues with the normal powerup sequence. However, if errors are detected, the tests identify a possible fault and the computer executes the monitor program.

Monitor

The monitor is a primary software application, resident in the firmware of the CPU board. It contains a collection of simple programs that provide file loading and diagnostic capabilities.

TAMME Initialization

Initialization begins with plugging a bubble memory cartridge, containing the applications and the operating system, into TAMME. A terminal set at 9600 baud must be attached to TAMME's local user port. Power is applied first to the mining machine and then to the TAMME chassis. Shortly, thereafter, the diagnostic software SCT begins testing of the CPU and attached hardware. If all systems check okay, the operator can load the operating system by typing b. This action puts the system into the human interface level of the operating system (fig. 2). Selection of the applications software is made at the human interface level. The application software package created for the Joy 16 CM machine is called TAMME. Typing TAMME into the keyboard starts the application. The first part of TAMME creates a special software task called the watchdog timer, which is a software implemented safety device. Next, two user I-O jobs are created that provide menu-driven interfaces to a local terminal user and a remote terminal user. The system is now ready to perform any of the experiments as selected from the menus.

Watchdog Timer

This software task exists within the software application called TAMME, which is stored in the bubble memory cartridge. It is activated with the TAMME task and runs simultaneously with it. Its algorithm provides a CPU activity signal to external hardware. As long as the watchdog timer is executing, a particular bit on a digital output port is being toggeled. If the CPU experiences some failure, the watchdog timer task will stop and its output signal quits toggling. External hardware, attached to the watchdog timer port, expects to see a toggling signal. When the toggling quits, power to computer control

circuitry is removed, thereby disabling the Joy 16 CM mining machine. This application was primarily instituted as a safety device because of the potential danger that an out-of-control, 50-st mining machine presents.

LOCAL USER OPERATION

The local user is the primary operator of the system. All of its features are provided through a menu-driven interface. The operator simply selects a function, provides parameters, and initiates a process. This section is a descriptive tutorial on the capabilities of the TAMME system. The information is presented this way because its the best method to detail the individual processes. Figure 5 is a menu flowchart detailing the menu operation.

```
                    MENU 1
*****************************************
System Exerciser Mode

1.  system diagnostics
2.  system exerciser
3.  closed loop tests
4.  browser mode
5.  scripting mode
6.  exit

enter (1-6) ->
*****************************************
```

System Exerciser Mode

The system exerciser permits the operator to test all controllable appendages on the machine without involving the use of any feedback sensor or other position determining devices. The machine appendages are called primitives and are grouped into the types of control they provide. They include the latching primitives and momentary primitives. The latching primitives are appendages on the machine that are designed to be turned on or off for the duration of some part of a mining cycle. The momentary primitives are appendages that are used in short spurts during mining cycles. Testing of a primitive is done by first selecting a primitive type, and then entering an execution parameter. The selected appendage will then move in respect to the execution parameter.

When the operator selects the system exerciser mode of operation, menu 2 is displayed. Here, the type of primitive function is selected.

```
                    MENU 2
*****************************************
System Exerciser

1.  latching primitives
2.  momentary primitives

enter (1-2) ->
*****************************************
```

Latching Primitives

The latching primitives are a group of four machine-controllable functions that are designed to be latched on or off for the duration of a mining cycle.

The latching primitive menu (menu 3) comes up first with the present status and then with a selection of control. As the operator selects an item he or she is prompted with menu 4. Exiting menu 4 causes the Joy 16 CM to perform the selected operation.

```
                    MENU 3
*****************************************
Latching Primitives Present Status

conveyor forward                off
pump run control                off
control power relay             off
cutting motor control           off

Latching Primitives Menu

1.  conveyor forward
2.  pump run control
3.  control power relay
4.  cutting motor control
5.  turn off all latching primitives
6.  exit

enter (1-6) ->
*****************************************
```

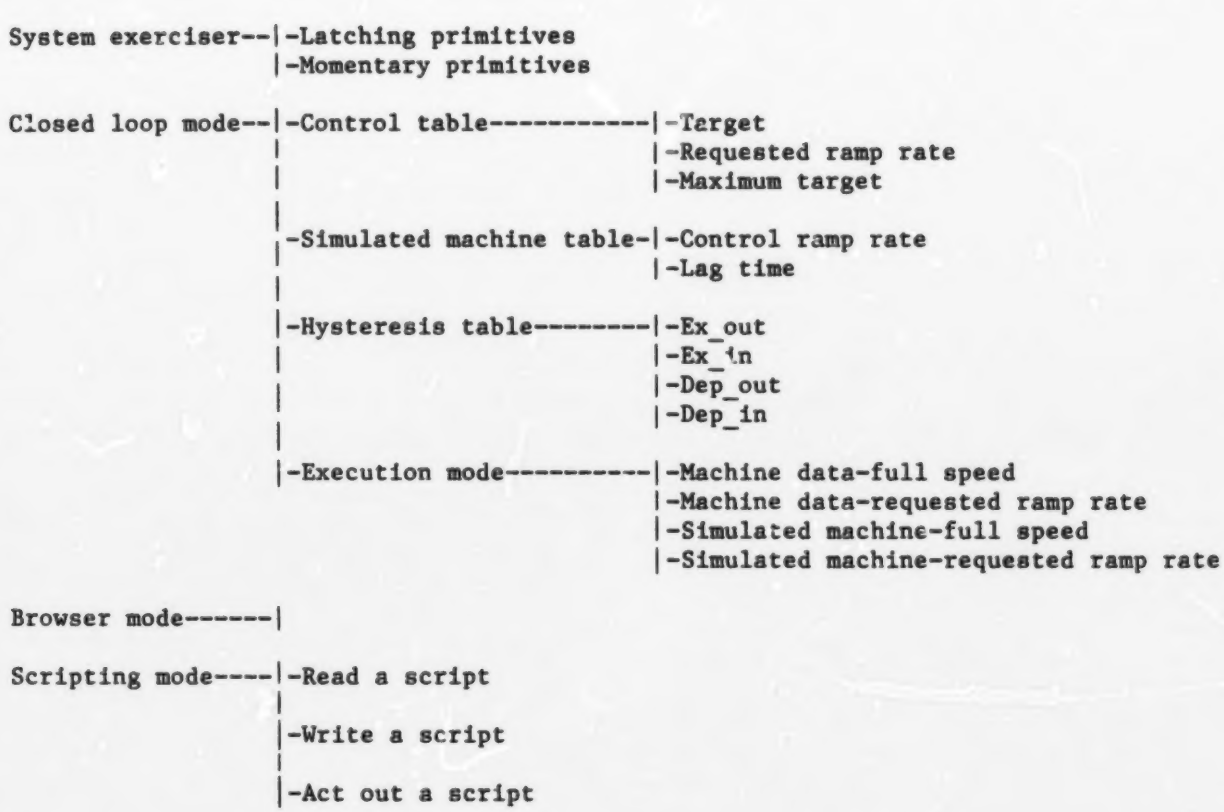

FIGURE 5.—Menu flowchart.

```
                MENU 4
*****************************************
conveyor forward
1 to turn on
2 to turn off

enter (1-2) ->
*****************************************
```

Momentary Primitives

The system exerciser menu (menu 2), item 2, provides control of the momentary primitives on the Joy 16 CM machine. The momentary primitives are appendages or other control devices that are designed to work intermittently during a mining cycle. Menu 5 provides the complete selection of available primitives. As a primitive is selected, the operator is asked to enter the amount of time that the primitive is to be executed. Entries from 0.01 to 99.99 s are permitted. Upon successful execution of a momentary primitive, an okay message is shown. Any error messages shown will indicate reasons for failures to complete a timed target value.

MENU 5

```
**********************************************************************************************
Momentary Primitives Menu

1-conveyor elevation up          2-conveyor elevation down      3-conveyor swing right
4-conveyor swing left            5-control safety latch         6-gathering head down
7-gathering head up              8-drum extension in            9-right tram slow
10-left tram slow                11-right tram reverse          12-left tram reverse
13-right tram forward            14-left tram forward           15-fast tram
16-drum extension out            17-stab jack up                18-stab jack down
19-gathering head ext in         20-gathering head ext out      21-conveyor reverse
22-shear up                      23-shear down
24-tram lo speed forward         25-tram high speed forward     26-tram lo speed reverse
27-tram hi speed reverse         28-tram forward turn right     29-tram forward turn lt
30-tram reverse turn rt          31-tram reverse turn left      32-pivot right
33-pivot left                    34-return to main menu

enter (1-34) ->
**********************************************************************************************
```

Closed Loop Test

When element 3 of the main menu (menu 1) is selected, the operator is presented a menu (The closed loop control menu--menu 6) through which a machine appendage can be tested for accurate positioning when using sensor feedback for validation. In the tests, embedded software algorithms compensate for machine control variables such as gear backlash and hydraulic response times. The primary control algorithm is called the servo. In servo, a requested target value is pursued by activating the appropriate machine appendage and monitoring the output from the sensor attached to the appendage. As the machine appendage closes in on the requested target, then the algorithm deactivates the appendage control, which indicates the requested target was reached.

Operation of this mode begins by requesting the operator to fill in the tables provided by items 1, 2, and 3 of menu 6. Then the operator goes to the execution mode to select a primitive to test. The various tables and menu items are described in the following sections.

MENU 6

```
*****************************************
Closed Loop Control Menu

1.  control table
2.  simulation table
3.  hysteresis table
4.  execution mode
5.  exit

enter (1-5) ->
*****************************************
```

Control Table

The first table the operator must fill in is the control table (see menu 7). This table identifies each of the machine primitives and shows operator changeable parameters including a target, a requested ramp rate, and a maximum target. These operator changeable items are described in the following sections.

MENU 7

```
**********************************************************************************************
Closed Loop Control Table

Function                    Target(deg)    Req_ramp_rate(deg/sec)    Max_target(deg)
 1-conveyor                    1.23                 4.7                    20
 2-conveyor swing              2.45                 5                      95
 3-shear                      24.66                 3.1                    45
 4-stab jack                   6.90                12.1                    25
 5-gathering head                10                 1.8                    24

Function                    Target(feet)                                Max_target(feet)
 6-tram slow                   11.3                                          200
 7-tram fast                   33                                            150
 8-tram reverse slow          121                                            140
 9-tram reverse fast          122                                            140

Function                    Target(deg)                                     360
10-pivot left                  45                                            360
11-pivot right                 22                                            180
12-tram reverse left           34                                            180
13-tram reverse right          50                                            270
14-tram forward left           23                                            270
15-tram forward right          12
select an operation
1-update  2-exit enter (1-2) ->
**********************************************************************************************
```

Target

The target value is a position in degrees or feet that the operator wants the primitive on the machine to achieve. The target value is actually the scaled output from a sensor or collection of sensors associated with a particular primitive. Presently, only primitives 1 through 5 use sensors to determine position.

Requested Ramp Rate

This parameter is associated only with the first five primitives. Its value is given by operator input, in degrees per second. The requested ramp rate is only used when the operator requires a primitive to operate at less than full speed, and then the speed is determined by the values supplied in this table item. The selection of using a requested ramp rate or full speed is provided through menu 10 (type of execution menu).

Maximum Target

The value entered into this table item, is used by the software to set the maximum allowable limit for a target, as determined by the scaled sensor output. This number is the maximum output that a sensor can provide under normal operating conditions. If this number is ever exceeded, the computer would indicate a possible hardware failure in the system. As a closed loop test is executed, values

from menu 7 are supplied to a software task.

Closed Loop Test, Execution Mode, Algorithm Description

The algorithms created for the execution mode are identified in figure 6. The operator begins execution by selecting a primitive; from then on, the process is automatic. There are five tasks that provide the closed loop algorithm. Each task is an independent piece of software that runs concurrently with each of the other tasks. The purpose for each task is described in the following sections.

Execute

Execute is created as soon as the operator selects a primitive function. The first step it performs is to collect data for the selected primitive from the appropriate data tables. Next, execute creates a second task called spawner. Then it goes into a sleep state where it waits for one of two possible occurrences; one, the operator interrupts the process; or two, the computer halts the process when the primitive achieves a target within the hysteresis band.

Spawner

The spawner task's purpose is to create the entire closed loop cycle. First the analog data task, then the servo task, and, finally, the ramper task is created. Spawner provides each of the tasks with primitive specific initialization data. After these tasks are created, Spawner dies.

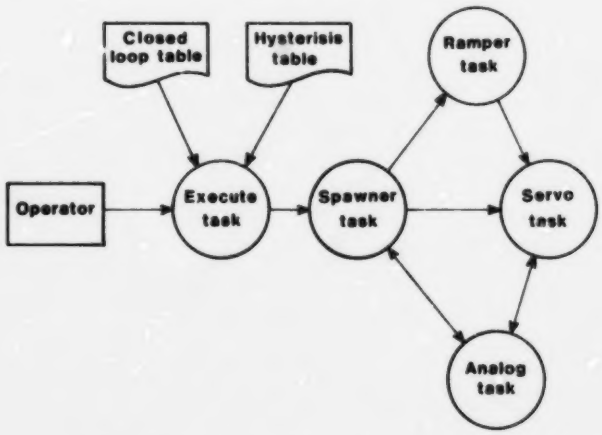

FIGURE 6.—Closed loop test algorithm.

Analog Data

This task continuously provides primitive specific, conditioned sensor data, as requested.

Servo

The servo algorithm begins by waiting for a message for a target value from the ramper to which a particular primitive is supposed to achieve. As soon as a target value is received, the present position of the primitive is determined, and is compared to the target value. If the primitive position is within the hysteresis boundaries of the target, then no action is taken. However, if the primitive position is outside the hysteresis boundaries of the target, then action is taken to move the primitive to the appropriate position.

Ramper

Ramper is a software task that outputs to the servo, varying numbers at a constant rate that represent target values. The numbers increase or decrease towards some final number that represents the final target. When the final target number is achieved, it is continuously output at a constant rate until the closed loop process is halted.

Simulated Machine Operation

Item 2 (simulation table) from the closed loop control menu (menu 6) provides a simulated machine, mode of operation, and is used only as a computer debugging tool, and is not used to control the mining machine. In fact, when this mode is used, the computer should not be connected to the mining machine. The numbers entered into the simulation table are used to cause a digital-to-analog (D-A) converter to simulate the

output of a particular sensor attached to a particular moving appendage on the mining machine. The creation of this mode was done primarily to permit the system developers to test software algorithms without having to use a 50-st mining machine to debug the software. Use of this mode requires that the outputs of the appropriate channels of a D-A card be attached to the appropriate channels of the analog-to-digital (A-D) converter card. The table provided to the user is shown in menu 8.

Descriptions of the operator changeable parameters for items in menu 8 follow.

Ctrl Ramp Rate

The numbers entered for each of the machine primitives are the actual rate at which the analog signal will change for a particular channel of the D-A card.

Lag time

The operator-entered number represents a machine constant for gear backlash and hydraulic system delays.

Hysteresis Table (See Menu 9)

This table (displayed when item 3 of menu 6 is selected) presents operator changeable parameters that take into account the inaccuracies associated with controlling machine appendages on the Joy 16 CM mining machine. The parameters Ex_out, Ex_in, Dep_out and Dep_in are positions in space about a target to which the appendage is to move. Use of these parameters, in the closed loop mode of operation, eliminate instabilities inherent in machine control environments. A

MENU 8

****

Simulated Machine Operation

Function	Ctrl_Ramp_Rate(deg/sec)	Lag_time(sec)
1-conveyor up	1.2	1
2-conveyor down	2.5	1.5
3-conveyor swing up	5.0	1.6
4-conveyor swing down	3.4	2.1
5-shear up	3.4	0.3
6-shear down	2.1	1.5
7-stab jack up	3.4	0.6
8-stab jack down	2.9	1.2
9-gathering head up	5.9	0.9
10-gathering head down	2.9	0.8

Function	Ctrl_Ramp_Rate(feet/sec)	Lag_time(sec)
11-tram slow	1.4	3.2
12-tram fast	3.2	1.9
13-tram reverse slow	4.3	1.2
14-tram reverse fast	6.8	0.7
15-pivot left	19.1	0.8
16-pivot right	19.1	0.5
17-tram reverse left	9.8	2.4
18-tram reverse right	2.4	0.6
19-tram forward left	15.1	0.9
20-tram forward right	20	2.3

Select an operation

1-update 2-exit enter (1-2) ->

****

more detailed description of these parameters will be subsequently published.[6]

When a closed loop cycle begins, values are taken from this table and are used to determine if the primitive is within a target window.

MENU 9

```
****************************************
Hysteresis Levels Table
(all parameters are in degrees)
```

Primitive	Ex_out	Ex_in	Dep_out	Dep_in
1-conveyor	1.6	1.3	1.45	1.2
2-conveyor swing	4.5	3.9	4.5	4.6
3-shear	2.7	0.4	2.9	0.4
4-stab jack	4.0	2.3	4.0	1.6
5-gathering head	2.9	2.2	2.9	2.2

```
Select an operation
1-update  2-exit  enter (1-2) ->
****************************************
```

Execution Mode

This is a working part of menu 6. From here, machine cycles are executed based on parameters entered in the tables listed in the closed loop control menu. Entry into this mode begins as shown in menu 10. From this menu, there a four selectable types of execution. A description for each is provided in the following text.

MENU 10

```
****************************************
Type of Execution
1-machine data, full speed
2-machine data, requested ramp rate
3-simulated machine data, full speed
4-simulated machine data, requested ramp
   rate
5-exit this mode

enter (1-5) ->
****************************************
```

[6]For further information, contact John Sammarco, Pittsburgh Research Center, Bureau of Mines, Pittsburgh, PA.

Machine Data-Full Speed

This mode of operation causes a selected machine primitive to move from its present position, as determined by sensor input, to a particular target as set in the closed loop control table (menu 7) and as measured by sensor input. The machine primitive will move at the maximum speed possible, limited only by the physical characteristics of the machine.

Machine Data-Requested Ramp Rate

This mode of operation causes a selected machine primitive to move from its present position, as determined by sensor input, to a particular target as set in the closed loop control table (menu 7) and as measured by sensor input. The machine primitive will move at a software controlled ramp rate as determined by the Req_Ramp_Rate as input by the operator.

Simulated Machine Data-Full Speed

This mode of operation causes a selected computer output port to turn on and stay on until the software has concluded that a target was reached as determined by a simulated sensor input. The speed of execution is a measurement of the maximum response that can be expected from this set of hardware and software.

Simulated Machine Data-Requested Ramp Rate

This mode of operation causes a selected computer output port to cycle on and off at a software controlled ramp rate, until the software has concluded that a target was reached, as determined by a simulated sensor input. This cycle provides a base for testing closed loop control software algorithms.

After the mode of execution is selected, the operator selects the primitive he or she wishes to execute from menu 11.

```
                    MENU 11
*****************************************
Closed Loop Control Selector

1-conveyor
2-conveyor swing
3-shear
4-stab jack
5-gathering head
6-exit
select a primitive to execute (1-6) ->
*****************************************
```

Browser Mode

This mode is item 4 as selected from the main menu (menu 1). It gives the local operator a complete, instantaneous output from every sensor presently connected to the A-D converter card. The local terminal output is shown in menu 12.

```
                    MENU 12
*****************************************
Browser Mode Output

chan  0 = 00.00          chan  1 = 00.00
chan  2 = 00.00          chan  3 = 00.00
chan  4 = 00.00          chan  5 = 00.00
chan  6 = 00.00          chan  7 = 00.00
chan  8 = 00.00          chan  9 = 00.00
chan 10 = 00.00          chan 11 = 00.00
chan 12 = 00.00          chan 13 = 00.00
chan 14 = 00.00          chan 15 = 00.00
chan 16 = 00.00          chan 17 = 00.00
chan 18 = 00.00          chan 19 = 00.00
chan 20 = 00.00          chan 21 = 00.00
chan 22 = 00.00          chan 23 = 00.00
chan 24 = 00.00          chan 25 = 00.00
chan 26 = 00.00          chan 27 = 00.00
chan 28 = 00.00          chan 29 = 00.00
chan 30 = 00.00          chan 31 = 00.00
*****************************************
```

Scripting Mode

The scripting mode is a software application that permits the user to chain together a series of machine movements that can be executed with a single keystroke. As in all of the TAMME applications, it is menu driven. The operator activates it from the main menu (menu 1) by selecting item 5. The first screen (menu 13), displays three applications, which are described in the following section.

```
                    MENU 13
*****************************************
Scripting Mode Menu

1-read a script
2-write a script
3-act out a script
4-quit
enter (1-4) ->
*****************************************
```

Read a Script

This mode provides a directory of available scripts. Generally, the names of the scripts will be descriptive of the process to be performed. Menu 14 shows the contents of the setup script. Each element is numbered and the execution parameter is identified. The script, when executed, will begin with line number 1 and end with the last line number shown. Modification of a script must be done using the write a script Mode.

Write a Script Mode

There are nine possible scripts that can be created. Each has a built-in default identifier, but these can be changed as required as shown in menu 15. Creation of a script is as simple as answering a series of questions at the prompts provided (a prompt is represented by ->). Menus 16 through 18 show the operators interactions in the process of making or changing a script.

```
                    MENU 14
*******************************************
Script Directory

0 - setup
1 - tramtoface
2 - findstart
3 - firstcut
4 - produce
5 - fillshuttle
6 - backout
7 - movenew
8 - shutdown
9 - exit
Select a script to show (0-9) ->0

Script no. 1
Line #    primitive              execution
                                 parameter
1  control power relay             on
2  pump run control                on
3  control power relay             on
4  tram lo speed forward           12.45
5  left tram slow                   4.5
6  drum extension out               2.3
7  pivot right                      5.6
8  turn off all latches            on
*******************************************
```

```
                    MENU 15
*******************************************
Script Directory

0 - setup
1 - tramtoface
2 - findstart
3 - firstcut
4 - produce
5 - fillshuttle
6 - backout
7 - movenew
8 - shutdown
9 - exit
Select a script name to change (0-9) ->6
Enter the new name (maximum of 8 letters)
 ->backoff
*******************************************
```

```
                    MENU 16
*******************************************
Script Directory

0 - setup
1 - tramtoface
2 - findstart
3 - firstcut
4 - produce
5 - fillshuttle
6 - backout
7 - movenew
8 - shutdown
9 - exit
Select a script to change (0-9) ->1

Script no. 1
Line #    primitive              execution
                                 parameter
1  control power relay             on
2  pump run control                on
3  control power relay             on
4  tram lo speed forward           12.45
5  left tram slow                   4.5
6  drum extension out               2.3
7  pivot right                      5.6
8  turn off all latches            on

Script can be 20 lines long
Enter 21 to exit
Select a line in the script to change
 (1-21)->6
*******************************************
```

```
                    MENU 17
*******************************************
The script ends at the first disabled
 line.

Enter 1 to enable this line
Enter 2 to disable this line ->1

Do you want a new primitive.  Enter (y-n)
 ->y
*******************************************
```

MENU 18

****

Select a primitive

Momentary Primitives

1-conveyor elevation up	2-conveyor elevation down
2-conveyor swing right	4-conveyor swing left
5-conveyor reverse	
6-shear up	7-shear down
8-stab jack up	9-stab jack down
10-gathering head up	11-gathering head down
12-gathering head ext in	13-gathering head ext out
14-drum ext in	15-drum ext out
16-right tram slow	17-left tram slow
18-fast tram	
19-right tram forward	20-left tram reverse
21-right tram reverse	22-left tram reverse
23-tram lo speed forward	24-tram high speed forward
25-tram lo speed reverse	26-tram high speed reverse
27-tram forward turn right	28-tram forward turn left
29-tram reverse turn right	30-tram reverse turn left
31-pivot left	32-pivot left
Latching Primitives	34-pump run control
33-conveyor forward	36-cutting motor control
35-control power relay	38-exit
37-turn off all latches	

select one ->22

For timed primitives enter seconds (0.01 to 99.99)
For latching primitives enter (1) for on and (2) for off
enter here ->1.45

****

Remote User Operation

A remote user port is provided by TAMME through its operating system and hardware (fig. 1). This is a serial port than can be used in a number of ways. A dumb terminal can be attached and operate the system. A personal computer (PC) can be attached, and then operate the system using terminal emulation software. A modem can be attached, which will allow any number of remote computers to gain access to TAMME using standard modem communication software. Remote operation has been confirmed using the following machines: Symbolics 3600, Corona Data System PC, and Intel 310.

Since this is a multitasking, multiuser system, both the local user and the remote user can simultaneously interact with the Joy 16 CM. One user can be operating the machine, and another can be doing diagnostics. Or in a carefully orchestrated experiment, both users can run the machine. The range of possibilities are large but careful planning is crucial.

So far, the interactions through the remote port have been accomplished through menu-driven interfaces. The menu items are a limited set of what is available to the local user. There is, however, a special function now being built into the menu, that allows the remote port to communicate in a computer-to-computer fashion, rather than in a human-to-computer fashion, such as using menus. It employs a simple protocol.

SUMMARY

The first step towards making a Joy 16 CM mining machine is now complete. The fundamental performance characteristics, under computer control, have been determined. The next areas of activity will be to experiment with a variety of devices that will ultimately give the machine knowledge of its position in respect to the coal, the roof, and the general work area. Additionally, experiments will be performed in the areas of machine health, fault diagnosis, and interaction with mining machine support equipment. All of these experiments will begin as independent entities. As they evolve and produce practical hardware and software, they will be integrated within the TAMME system. To facilitate this evolution, TAMME is presently being enhanced by connection of a high-speed, multitasking, distributed, microcontroller-based network. TAMME will act as the master in this network. The newly developed application devices, hardware, and software will be attached to a node in the network, as shown in figure 7 (a node is one microprocessor, which has built-in communication and intelligent control algorithms). Data transferred between a node and TAMME will be very high level. This mode of operation will relieve TAMME of detail work and permit it to concentrate on its main function being process orchestrator.

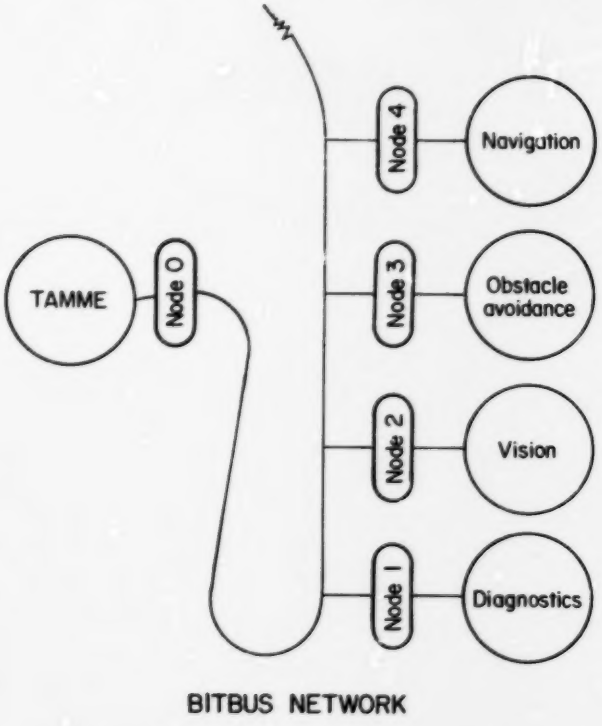

FIGURE 7.–TAMME and bitbus network.

The Bureau has developed a tool that provides access to mining machines, through which researchers can perform experiments, toward the goals of increased production and operator safety. Software algorithms provided by TAMME allow experimenters to completely define the control characteristics of a machine and then implement these characteristics in higher level software programs. With these higher level programs the TAMME system demonstrated control accuracy that is far superior to what a human operator can provide. Remote user operation of machine functions proves that other computers can be added to the system for additional system enhancement.

Although TAMME was constructed to be a research tool, its flexible design makes it easily reconfigurable to a production tool. In fact, some of the software algorithms already created could be used for production without any changes. And even though the hardware was set up for a Joy 16 CM machine, its modular I-O configuration can be quickly adapted to most any machine by simply changing a plug-in module.

The development and documentation of this system is provided in hopes of making it easy for others to pursue the goals of making coal mining more economical and safer.

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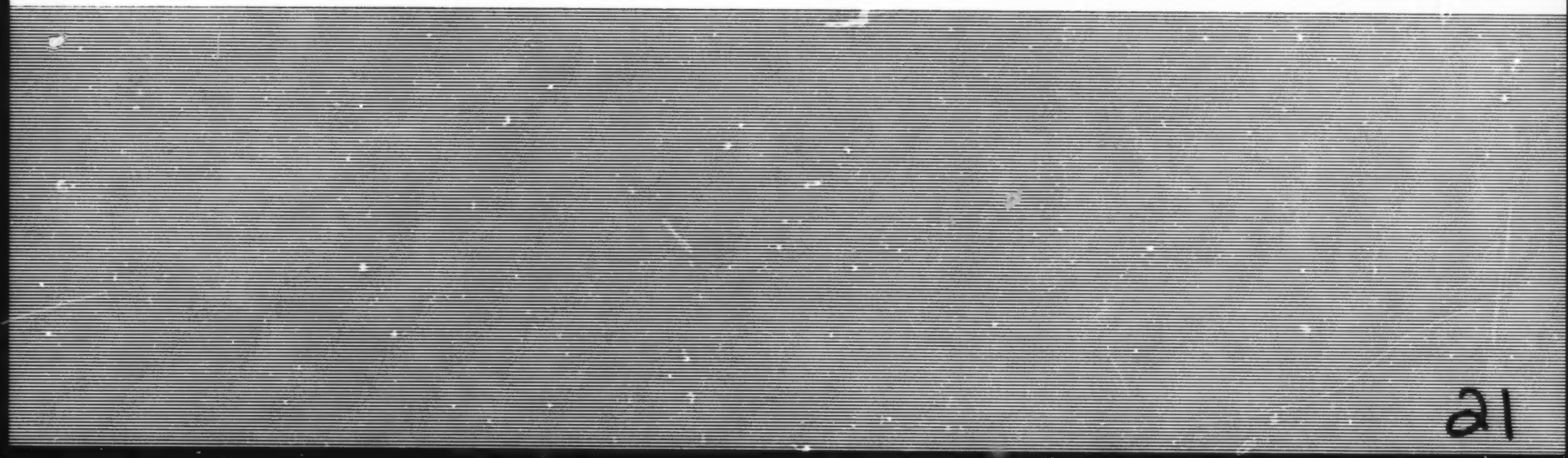

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